Very High Load Capacity Air Bearing Spindle for Large Diamond Turning Machines

Contract No. NNX10CF18P (SBIR 2009-1) (MSFC)

Mirror Technology SBIR/STTR Workshop

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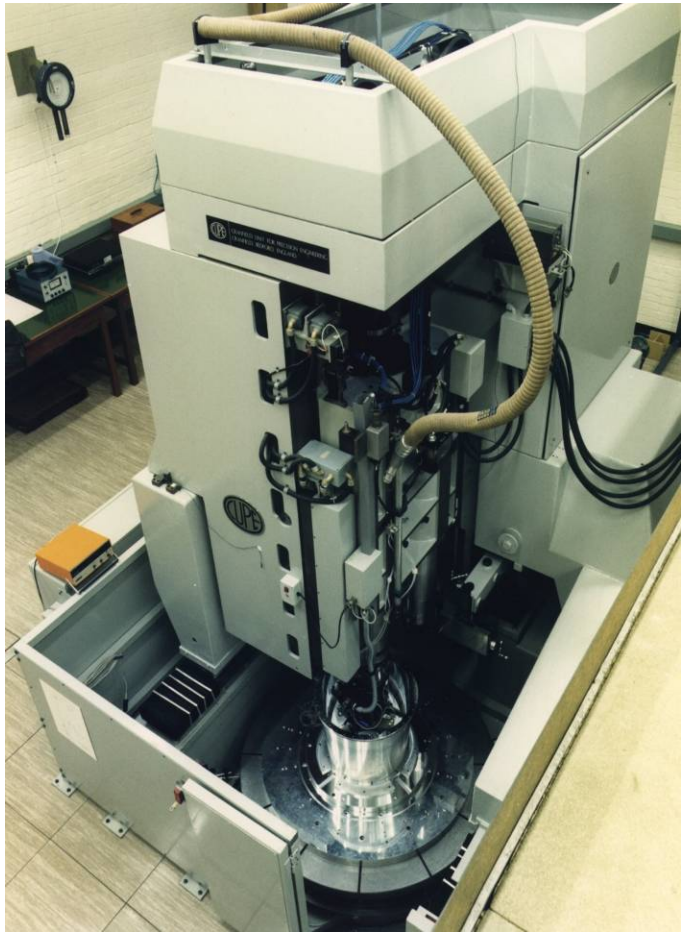
OUTLINE

- INTRODUCTION
- AIR BEARINGS vs. OIL HYDROSTATIC BEARINGS
- PROTOTYPE SPINDLE DESIGN
- PROGRESS TO DATE
- FUTURE WORK & SUMMARY

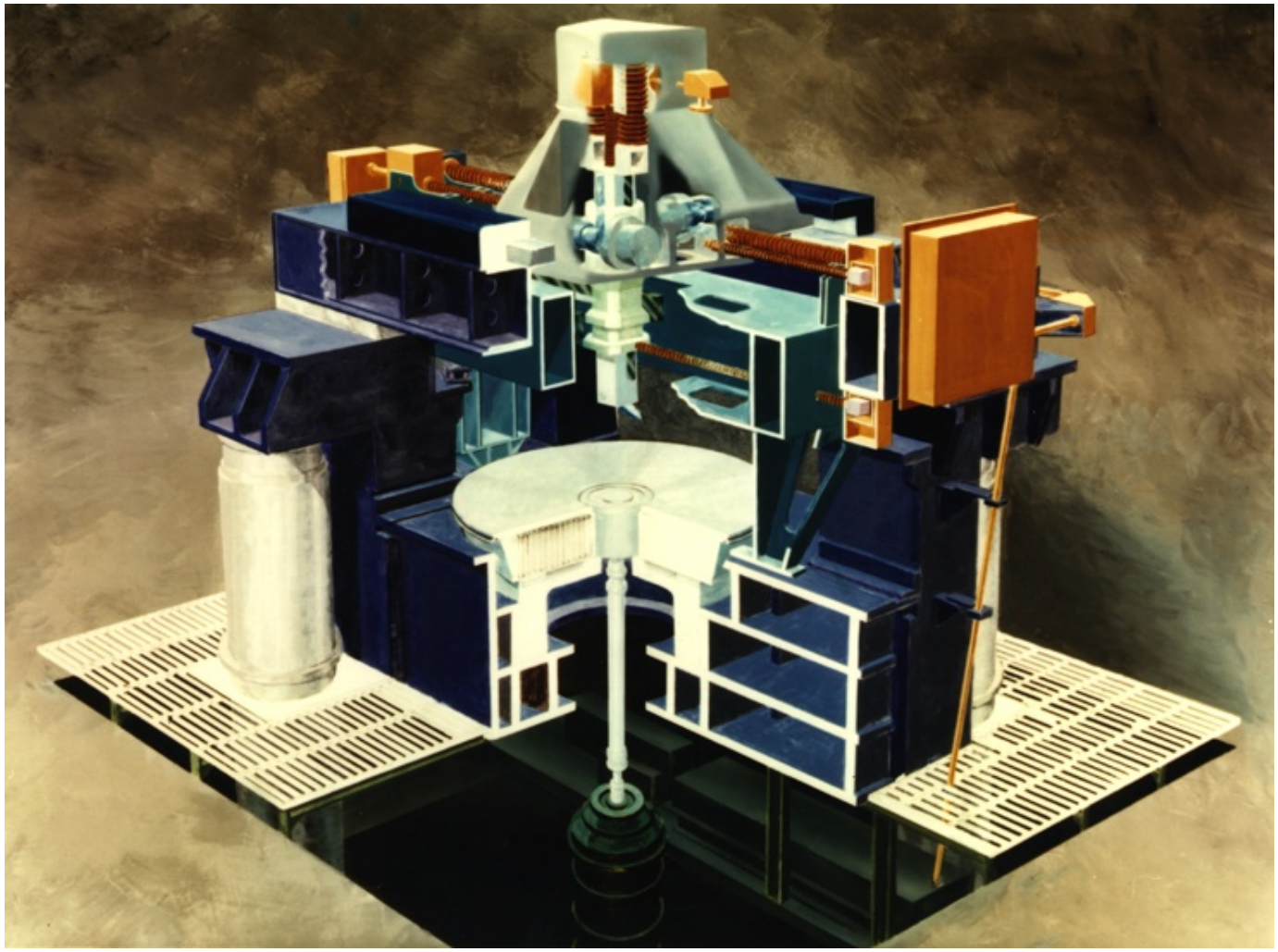
Introduction

- DT is a proven method of manufacturing aspheric off-axis mirrors to visible quality.
- Vertical turning machines are used for very large and heavy parts.
- The need for very large diamond turning has been recognized for at least 30 years.
- Attempts to meet the need have all failed because no suitable spindle was available.
- Oil hydrostatic spindles large enough to carry the load cannot run fast enough because of viscous frictional heat generated as the 4^{th} power of the bearing radius.
- Air bearings can run at sufficiently high speed to be practical because the viscosity of air is three orders of magnitude less than the lightest liquid lubricant.
- Classical metal to metal air bearings do not work for very large capacity because of prohibitive cost and catastrophic failure modes.
- Porous graphite air bearings are proven to be sufficiently rugged and reliable.
- Development of a giant capacity air bearing spindle is enabling technology for a giant diamond turning machine suitable for manufacture of giant aspheric optics.

Cranfield Precision (CUPE) – LDTM 1982



LLNL 1983 – Large Optics Diamond Turning Machine



Comparison of Oil Hydrostatic and Air Hydrostatic Bearings

Oil hydrostatic bearings tolerances are 25-75 microns (0.001-0.003")

Oil hydrostatic bearings and air hydrostatic bearings both have flow induced instability issues "water hammer" which must be carefully controlled.

Oil viscosity provides important squeeze film damping which aids control of flow induced instability. Air bearings are very much more sensitive to water hammer effects.

Viscous shear frictional heating limits large oil hydrostatic spindles to less than 100 rpm. This slow speed is unacceptable for diamond turning because the finish requirements of optics require a very small tool advance per revolution.

Dimensional accuracy requirements demand extreme thermal stability and this requirement increases with part size. The large heat generation of oil hydrostatic spindles at even unacceptably low spindle speeds is a severe problem.

Air bearing tolerances are extremely small because of the requirement that the air film must be no greater than about 6 microns (0.0003") to provide the required very high bearing stiffness for diamond turning. Flatness, roundness, squareness < 0.5 μm (0.00002").

Spindle Requirements for Giant Optics Diamond Turning

Fixture weight is usually orders of magnitude heavier than the optic it is designed to hold in a strain-free condition. This spindle development is aimed at producing 3 meter diameter components. This requirement results in the following spindle specification goal.

Working load capacity: > 89,000 N (20,000 lbf.)

Rotational speed: > 1000 rpm

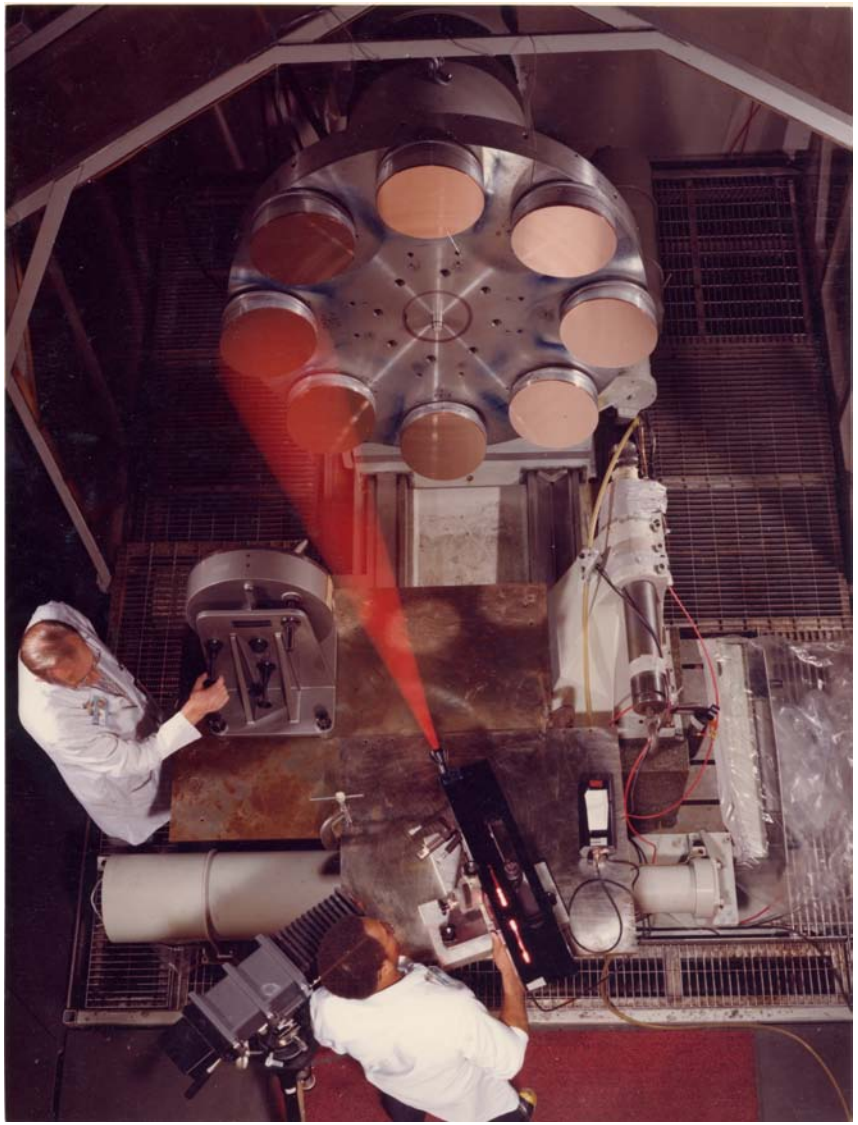
Max. spindle motion error, radial, axial, tilt: < 125nm (5μ inch)

2.48 Meter Aluminum Mirror Weight: 3000 lb.
Fixture Weight: 3000 lb.
Spindle Thrust table weight: 3000 lb.

Porous Graphite Air Bearing Technology

Porous graphite air bearings for ultra-precision turning where developed starting in the early 1960's at the Oak Ridge, Tenn. Y-12 Plant for use in manufacture of nuclear weapons components. This spindle development utilizes the experience of the principal investigator and various others at Oak Ridge in building large air bearings.

Y-12 Graphite Air Bearing 2.4 Meter Diamond Turning Machine



Prototype Air Bearing Spindle

A prototype air bearing spindle will be used as a vehicle for developing the manufacturing methods to be used on the larger air bearing suitable for use as part of a very large diamond turning machine.

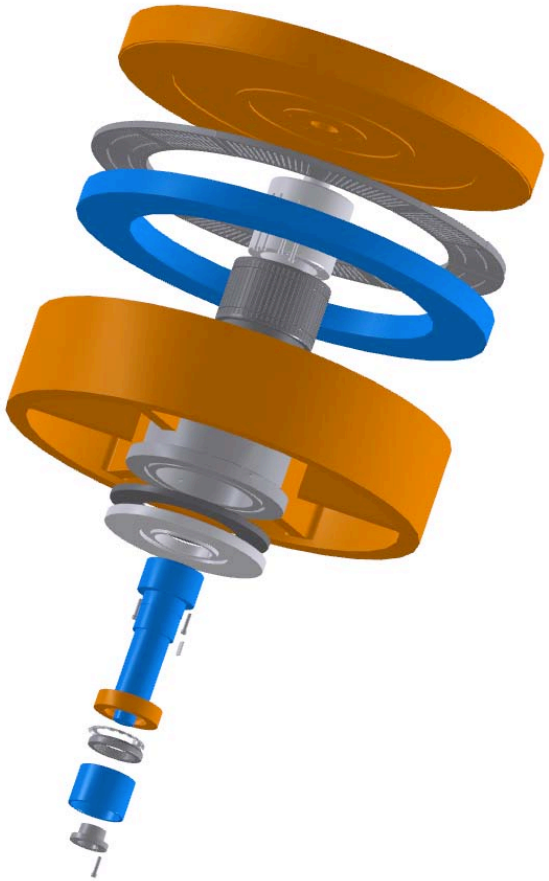
Major precision components of the air bearing spindle.

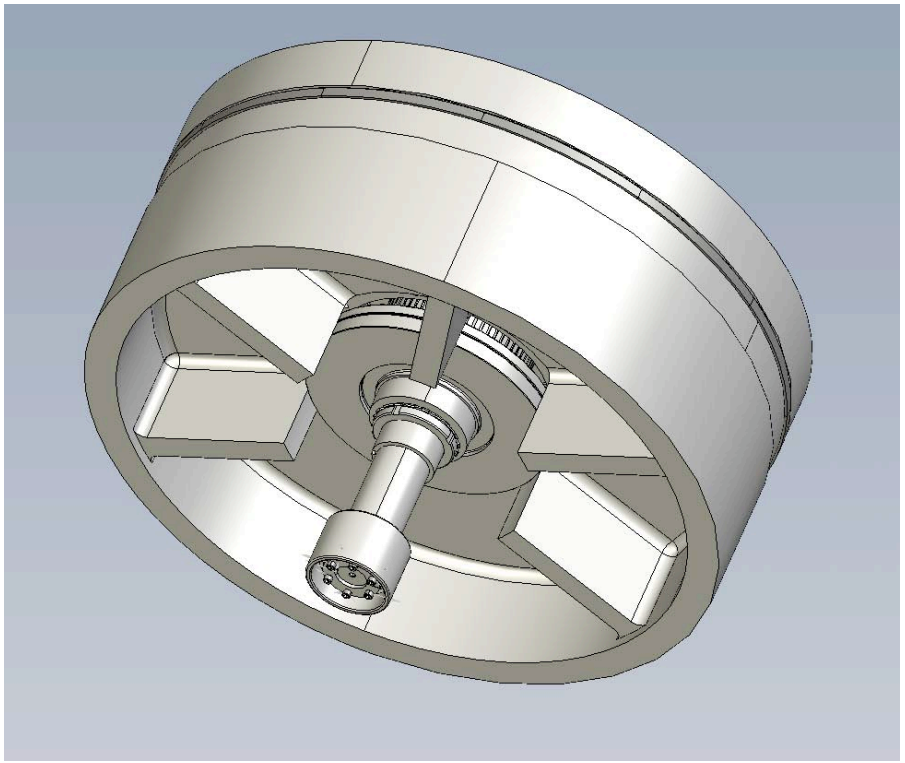
- **Flat thrust bearing plate/spindle faceplate. (lapped)**
- **Main thrust bearing graphite bearing material. (lapped)**
- **Radial bearing shaft. (Diamond turned NiP plated steel.)**
- **Radial graphite bearing. (Lapped to size w/ DT laps.)**
- **Bearing pre-load components. (Smaller porous bearing.)**
- **Spindle drive shaft and pulley. (Flat belt drive.)**
- **Spindle housing and air supply plumbing.**

SURPLUS METAL TO METAL AIR BEARING ROTARY TABLE

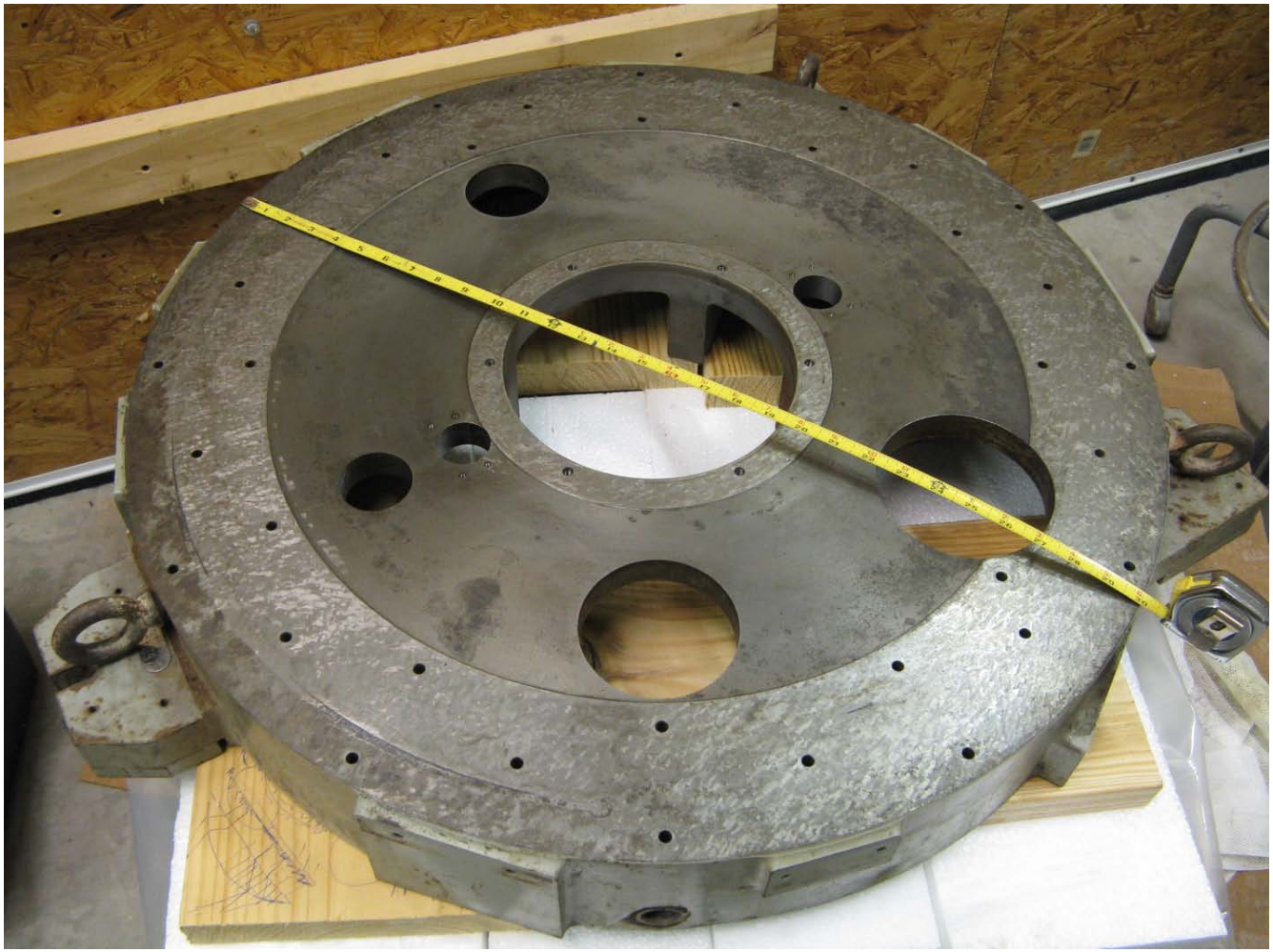
PROTYPE AIR BEARING SPINDLE DESIGN

Drawings for all the components of the prototype spindle are complete and fabrication of the required metal components is underway at this time.
Expected load capacity of the prototype spindle: 16,000 lb. max; 8000 working cap.

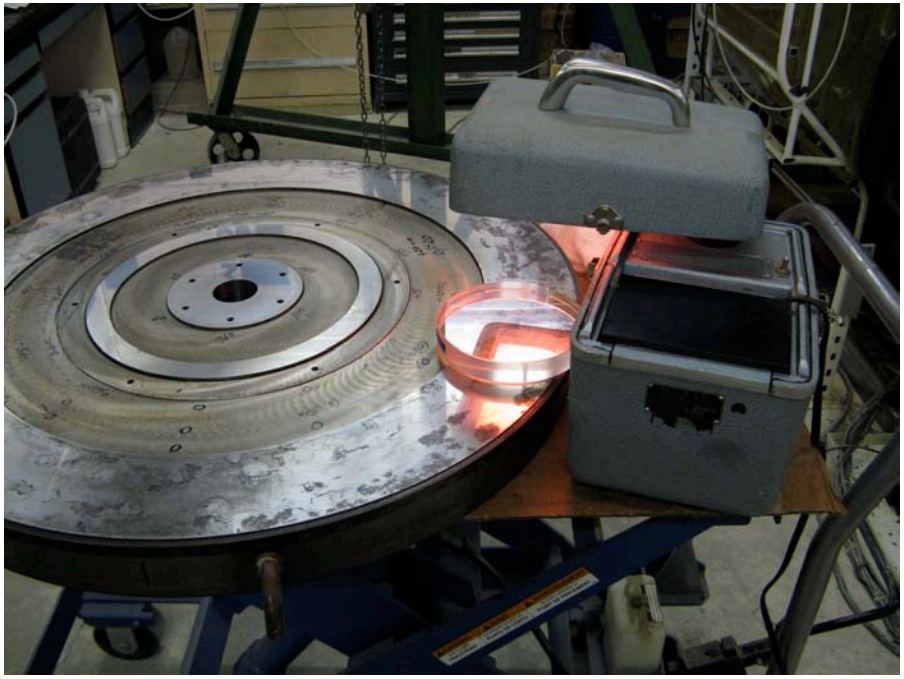


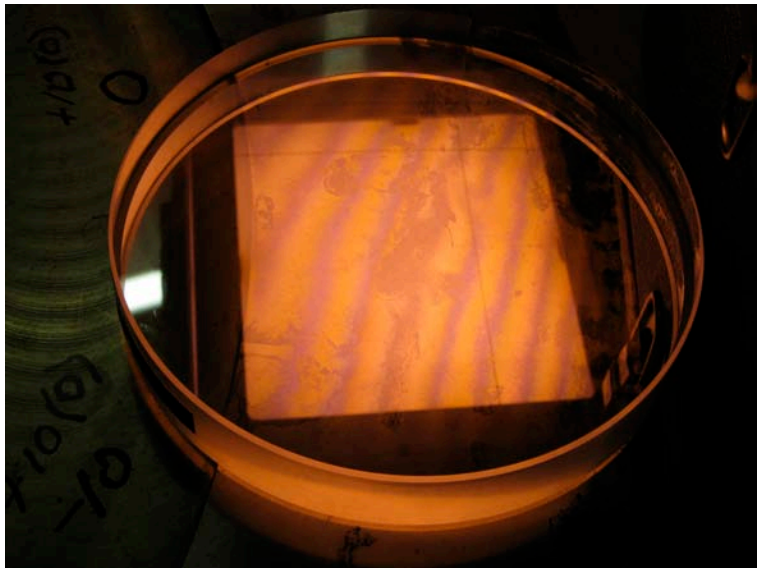


Housing of Air Bearing Rotary Table Modified for Porous Graphite



FLATNESS TESTING BEARING FACE OF 30” DIA. AIR BEARING ROTARY TABLE



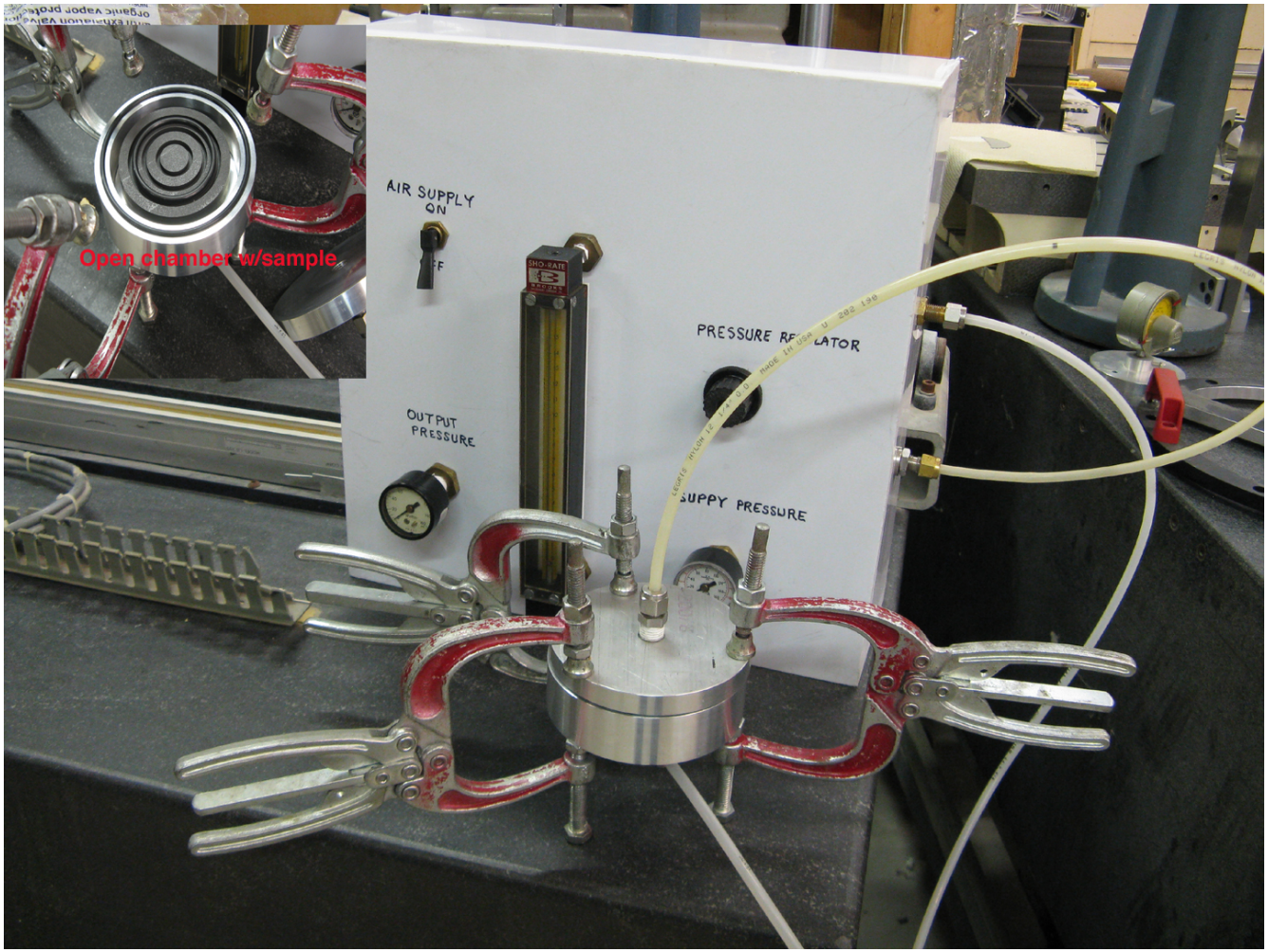


Steel Components of Porous Graphite Air Bearing Spindle

POROUS GRAPHITE TEST AND SELECTION

- Porous graphite samples are being tested to determine air flow properties.
- Selected graphite material is fabricated into test bearings for evaluation of impregnation and stability against “water hammer” flow induced instability.
- The bearing performance testing will select graphite grade for fabrication of the large air bearing parts.
- Eight graphite grades from five suppliers have been tested additional samples are in in testing at this time.

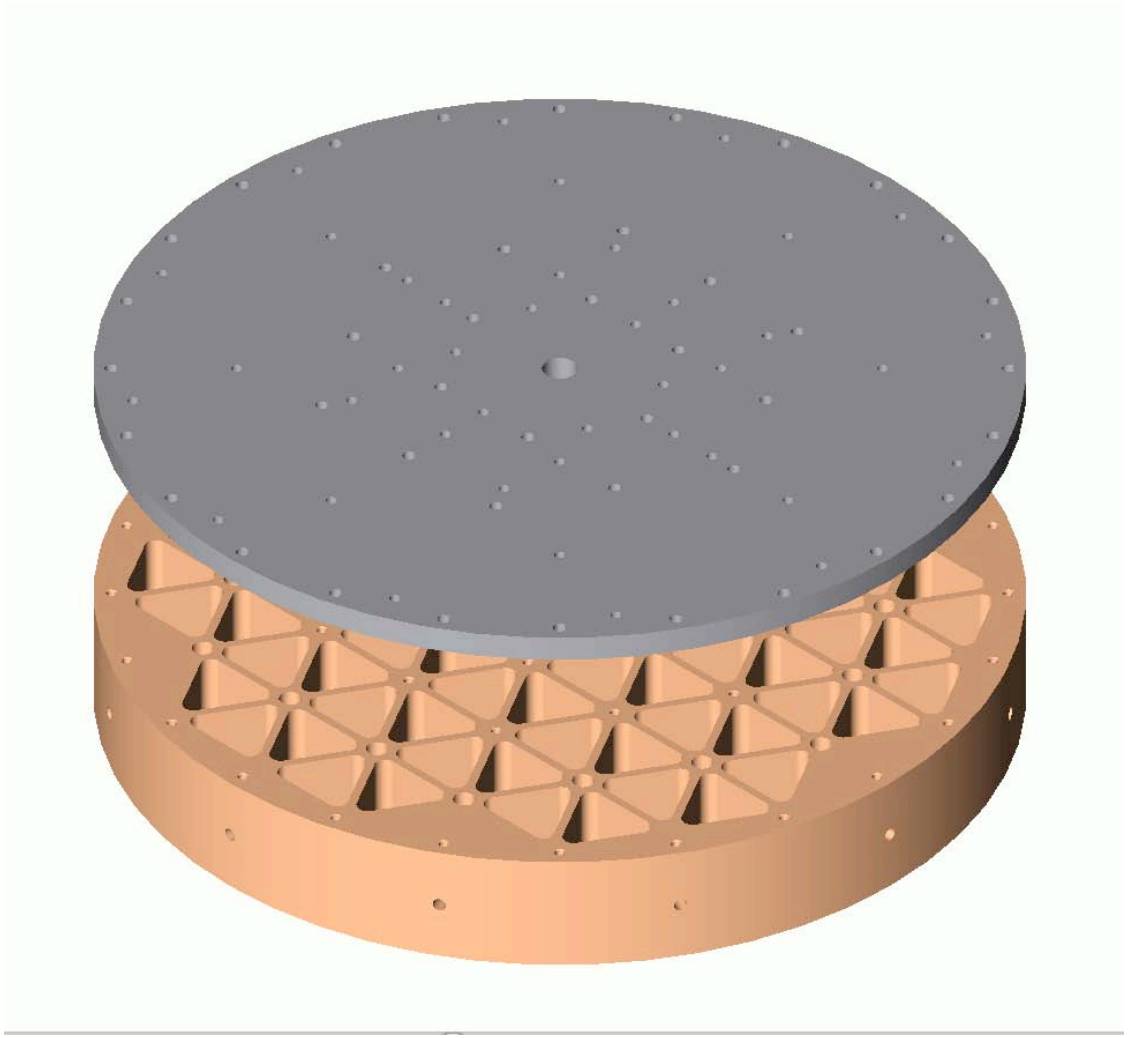
Flow testing sample disks of porous graphite



Porous Graphite Air Bearings For Flow and Stability Testing

Diamond turning of an X-ray telescope mandrel is a similar process to be used in diamond turning the air bearing radial bearing shaft.

Design of 98KN (20,000 lb.) Capacity Air Bearing Spindle



ULTIMATE GOAL IS A 3 METER DIAMOND TURNING MACHINE

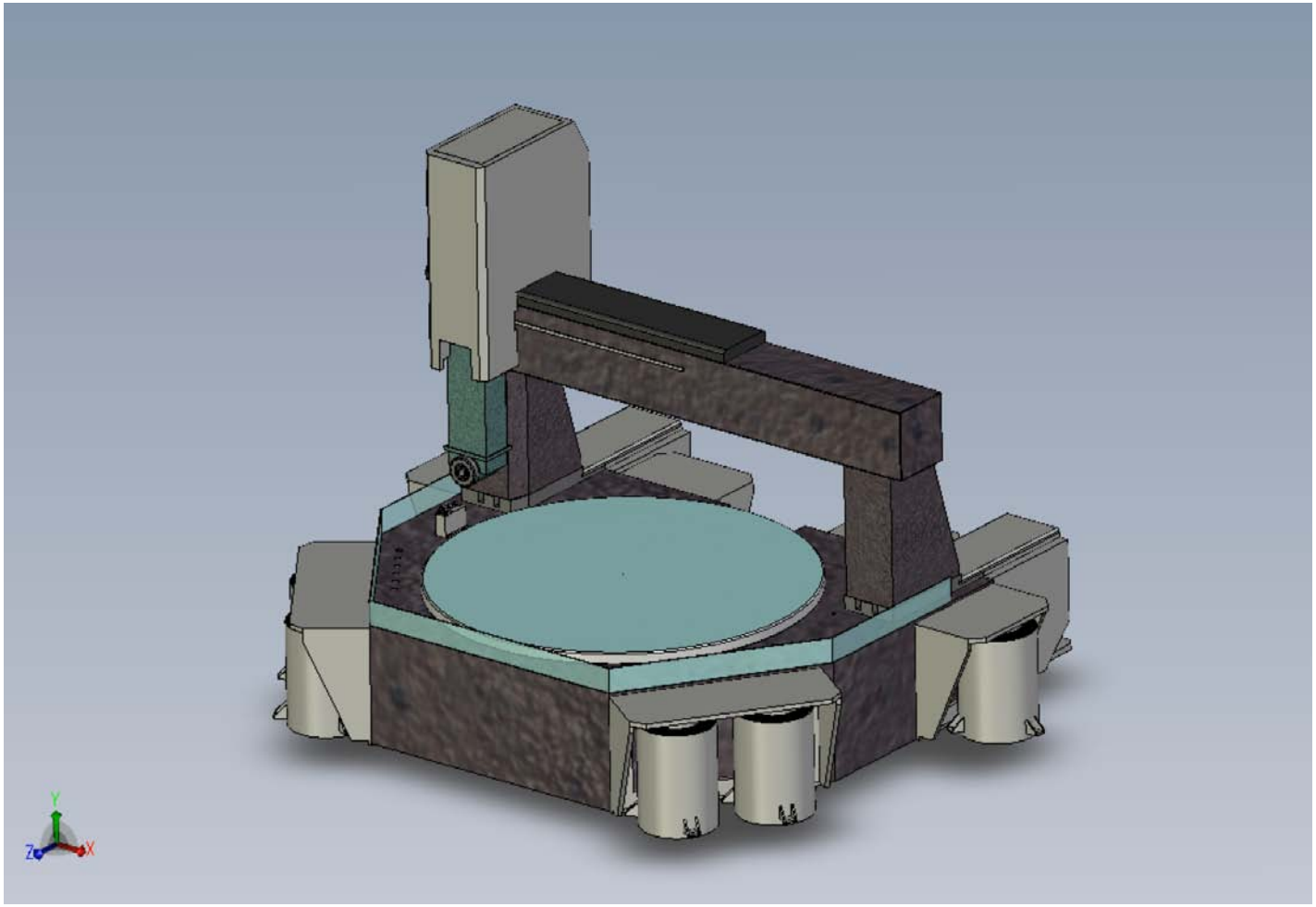
THE CRITICAL REQUIREMENTS FOR SUCCESSFUL DIAMOND TURNING OF OPTICAL COMPONENTS IN ORDER OF IMPORTANCE

1. **EXTREMELY SMOOTH AND ACCURATE SPINDLE.**
2. **EXTREMELY CONSTANT TEMPERATURE.**
3. **VERY ACCURATE AND HIGH RESOLUTION MACHINE CONTROL.**
4. **VERY ACCURATE AND REPEATABLE MACHINE MOTION.**

THERE ARE MANY OTHER REQUIREMENTS BUT THE FOUR ABOVE ARE ESSENTIAL.

MOORE TOOL CO. IS ONE OF THE FEW MACHINE TOOL BUILDERS IN THE WORLD THAT HAS THE CAPABILITY AND EXPERIENCE TO BUILD VERY LARGE DIAMOND TURNING AND GRINDING MACHINES. DOS HAS WORKED WITH MOORE TOOL CO. FOR MANY YEARS IN BUILDING LARGE DIAMOND TURNING MACHINES.

Moore Tool Co. Three Meter Diamond Turning Machine Concept



SUMMARY

Diamond turning can directly produce visible quality highly aspherical surfaces with machined reference surfaces to allow easy alignment of multiple complex optical contours.

Diamond turning enables high rate production of large highly aspheric mirrors at a cost an order of magnitude less than conventional optical fabrication methods.

- **A very large load capacity porous graphite air bearing is the critical enabling feature of a practical very large optics diamond turning machine.**

- **The prototype high speed porous graphite air bearing being developed by this SBIR is the technical path to the required 10 ton load capacity super precision air bearing.**

- **A diamond turning machine utilizing the new spindle will be capable of diamond turning and/or contour grinding 3 meter optical components will drastically reduce large optical systems cost.**